Apparatus and method for 3D-x-ray imaging

The invention relates to an apparatus for 3D-x-ray imaging of an object, comprising a system having an x-ray source and an x-ray image detector which both are adjustable with respect to the object in order to obtain in use at least one series of 2D-images of the object, and a processor connected to the detector for calculating a 3D-image of the object derived from the series of 2D-images.

Such an apparatus is known from US patent no. 5,852,646.

This known apparatus employs a C-arm to which an x-ray source and an x-ray image pick-up device are attached. The C-arm can be moved to a plurality of exposure positions along a (semi-)circular path in order to form a series of 2-dimensional x-ray images from different perspectives along said (semi-)circular path.

Generally the known apparatus comprises a memory unit that is connected to the processor for storage and retrieval of the 2D-images of the object under examination that are acquired during the motion of the C-arm.

A problem of the known apparatus relates to the limited contrast resolution of the x-ray image detector. Generally said contrast resolution is limited to approximately 10 bits.

Particularly when 3D-images are to be reconstructed from the 2D-images resulting from differently angled projections, a higher contrast resolution of the image detector is required that is at least ten times higher. Particularly in case of low contrast imaging, also known as 'soft tissue imaging', this high contrast resolution is required to be able to perceive sufficient contrast detail without undue saturation of particular parts of the image.

To date, however, only high contrast imaging of, for instance, contrast filled blood vessels and bone is known in which the soft tissue can not be identified due to, amongst others, the just-mentioned problem of saturation.

It is therefore an object of the invention to be able to provide 3D-images with extended contrast resolution as compared to the prior art.

The apparatus according to the invention is to this end characterized in that the system operates at different intensity levels to at least obtain a first series of 2D-images at a

low intensity level and a second series of 2D-images at a high intensity level, and which low intensity level is predetermined at a point to substantially avoid saturation of the x-ray image detector, and that the processor is arranged to merge the images from the first series of 2D-images with corresponding images from the second series of 2D-images prior to calculating the 3D-image.

With the apparatus of the invention the contrast resolution of the x-ray image detector may be substantially enhanced for example, to virtually fourteen bits, as compared to the known ten bits of the apparatus according to the prior art. Also 3D-images of the required contrast resolution can be obtained with the apparatus according to the invention thereby merely using a conventional x-ray image detector such as an image intensifier.

A further benefit of the apparatus according to the invention is that data acquisition is possible with only a moderate increase of the level of radiation exposure to the patient under examination.

Naturally the low intensity level may be obtained before the high intensity level or vice versa. In connection with this application "low" and "high" should be understood in relation to each other.

Advantageously pixels of the images of the second series of 2D-images above a predetermined threshold are replaced by corresponding pixels of images from the first series of 2D-images, and the thus merged 2D-images are subsequently used to calculate the 3D-image. This operation can be easily implemented and does not require much computational effort, whereas the resulting images can be acquired with sufficient linearity over the entire dynamic range.

Beneficially the thresholding of the second series of 2D-images is performed at a predetermined level which slightly differs for neighbouring pixels of the 2D-images. This improves the quality of the resulting images and avoids undesirable spurious artefacts in the reconstructed images that are due to the processing of the images in relation to an otherwise fixed level of the threshold.

In a known apparatus the x-ray image detector comprises an image intensifier, and a diaphragm followed by a CCD or pickup tube. In this apparatus a possible embodiment is characterized in that the diaphragm is switched between settings corresponding to the low intensity level and the high intensity level of the 2D-images.

In a further and preferred embodiment however the known apparatus is characterized in that the x-ray source operates at different exposure levels corresponding to

the low intensity level and the high intensity level of the 2D-images. This limits the exposure level of the patient under examination.

In a further aspect of the invention the apparatus is characterized in that the first series of 2D-images and the second series of 2D-images are collected at mutually excluding time-frames. This allows for election of the images such that the individual images of the first series and of the second series share the same geometrical parameters. Merging of the images of the first series and the second series is then easy to implement.

In still another aspect of the invention the apparatus is characterized in that the subsequent images from the first series of 2D-images and the second series of 2D-images are collected alternatingly. This allows for a so-called interleaved collection of the images of the first series and the second series of 2D-images, causing a slight shift in geometrical parameters of the subsequent images. When merging these images, interpolation of images is required to remedy the difference in geometrical parameters. However, an advantage is that the collection of images of the first series and the second series of images can be executed at a single run. Also problems associated with movement of the patient during data collection are less important.

Particularly in the just-mentioned embodiment it is advantageous that the x-ray image detector is a flat detector imaging device. Such a flat detector imaging device allows for quick switching between high level intensity and low level intensity data collection. Such a flat detector imaging device is for instance known from the article *Innovations in flat-detector cardiac angiography* by J. Fajadet et al., published in MedicaMundi, 47/2, August 2003, pages 56-60.

The invention is also embodied in a method for acquiring a 3D-image of an object by collecting at least one series of 2D-x-ray images of the object wherein the images are taken from different angles, and the 2D-images are processed into the 3D-image.

The method according to the invention is characterized in that a first series of 2D-images is acquired at a low intensity level and a second series of 2D-images is acquired at a high intensity level, and which low intensity level is predetermined at a point to substantially avoid saturation of an x-ray image detector, and wherein the images from the first series of 2D-images are merged with corresponding images from the second series of 2D-images prior to processing same into the 3D-image.

Preferably in this method and prior to processing the 2D-images into the 3D-image, the pixels of the images of the second series of images above a predetermined threshold are replaced by the corresponding pixels of the images of the first series of images.

Furthermore, it is preferred in the method of the invention that the thresholding of the second series of 2D-images is performed at a predetermined level which slightly differs for neighbouring pixels of the 2D-images.

The invention is further embodied in a computer program for a processor of an apparatus as described here-above, which computer program is arranged to execute the just-mentioned method.

Also the invention is embodied in a data carrier which is provided with such a computer program.

The invention will now further be explained with reference to the drawing showing in a single figure an apparatus according to a non-limiting exemplary embodiment of the invention.

In figure 1 reference numeral 1 depicts the apparatus according to the invention in which a C-frame 10 is employed which is mounted on a stand 11 and which can be rotated over approximately 210° around its centre as indicated with the arrow 20. The C-arm 10 is provided with an x-ray source 12 as well as an x-ray image detector 13 and is intended to acquire images from a patient 3 being under examination and lying on a table 4 in a stationary position.

In order to collect a series of images the C-arm 20 moves in the direction indicated with arrow 20. In order to indicate same the figure shows also two positions of the x-ray source 12 and the x-ray image detector 13 in shaded lines.

The different components of the apparatus 1 are controlled by means of control unit 17 and whilst the C-arm 10 is moving data collection occurs by means of a device 14 that digitises the information from the x-ray image detector 13. The x-ray detector 13 could be an image intensifier as is known in the art. However, the x-ray detector 13 and the digitiser 14 can be combined in a so-called flat detector which directly provides a digitised image. Such a flat detector is known from the earlier mentioned article in MedicaMundi, 47/2, August 2003, pages 56-60.

Connected with a memory 15 in which data provided by the digitiser 14 van be stored, is a processor 16 which is used to derive a 3D-image from the collected 2D-images.

For the purpose of acquiring a 3D-image of sufficient contrast resolution capable to show contrast details of soft tissue and hard bones, the apparatus of the invention employs different intensity levels to obtain a first series of 2D-images Ai-1 – Ai+2 and a second series of 2D-images Bi-1 – Bi+2 at a second intensity level. Usually both series are stored in memory 15 after their collection.

The first intensity level of the series Ai-1 – Ai+2 is lower than the second level of the series Bi-1 – Bi+2.

The level at which the first series of 2D-images Ai-1 – Ai+2 is collected is predetermined at a point to substantially avoid saturation of the x-ray image detector 13.

The processor 16 to which usually a video display unit 18 is connected, is arranged to merge the images from the first series Ai–1 – Ai+2 of 2D-images with corresponding images from the second series Bi-1 – Bi+2 of 2D-images prior to calculating the 3D-image which is intended to be shown on the visual display unit 18.

The merger of the first series Ai-1 – Ai+2 of 2D-images with the corresponding images from the second series Bi-1 – Bi+2 of 2D-images is carried out preferably by replacing the pixels of the images of the second series Bi-1 – Bi+2 of 2D-images above a predetermined threshold by corresponding pixels of images from the first series Ai-1 – Ai+2 of 2D-images. The thus merged 2D-images can then effectively be used to calculate the 3D-image.

In this apparatus it is preferred that the thresholding of the second series Bi-1 – Bi+2 of 2D-images is performed at a predetermined level which slightly differs for neighbouring pixels of the 2D-images.

Usually, the x-ray image detector 13 may be embodied as an image intensifier followed by a diaphragm and a CCD or pickup tube to acquire a digital image. In order to operate the apparatus 1 at different intensity levels the diaphragm can then be switched between settings corresponding to the first intensity level and the second intensity level of the acquired 2D-images.

Advantageously, however, the x-ray source 12 operates at different exposure levels corresponding to said first intensity level and said second intensity level of the 2D-images in order to limit the radiation exposure of the patient 3 under examination.

The first series Ai-1 – Ai+2 of 2D-images and the second series Bi-1 – Bi+2 of 2D-images can be collected at mutually excluding time frames; i.e. immediately following each other. The two series then comprise images sharing the same geometrical positions at which the images were collected. The merger of both series can then be easily implemented.

In another embodiment it is preferred that the subsequent images from the first series Ai-1 - Ai+2 of 2D-images are collected alternatingly with the second series Bi-1 – Bi+2 of 2D-images. Subsequent images of both series then are less sensitive for movement by the patient 3 under examination. It is required then, however, to correct for the different geometrical positions in which the respective series of images are collected.